GZK neutrinos: Have we tried looking down?

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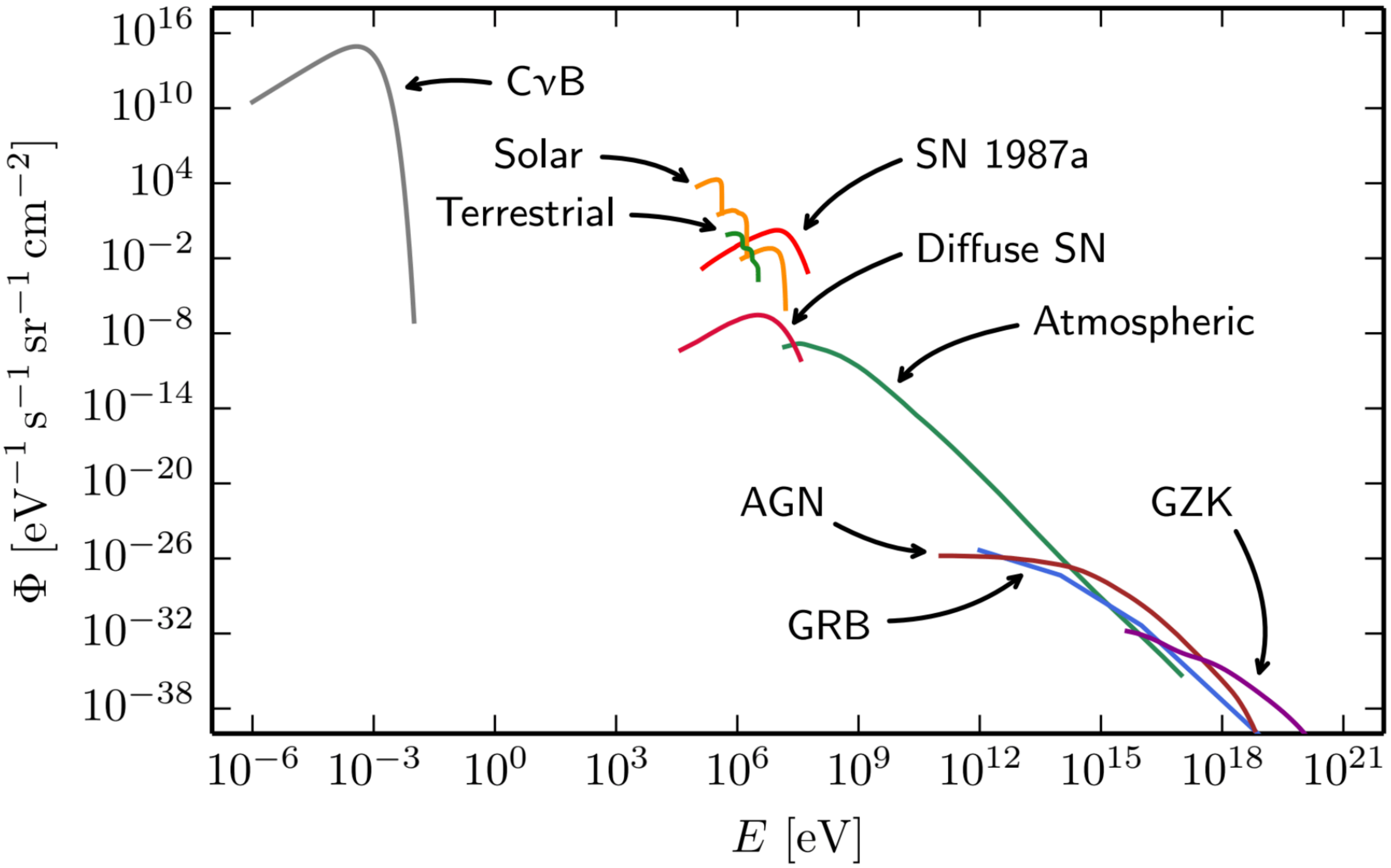
Based on arXiv:1909.10487

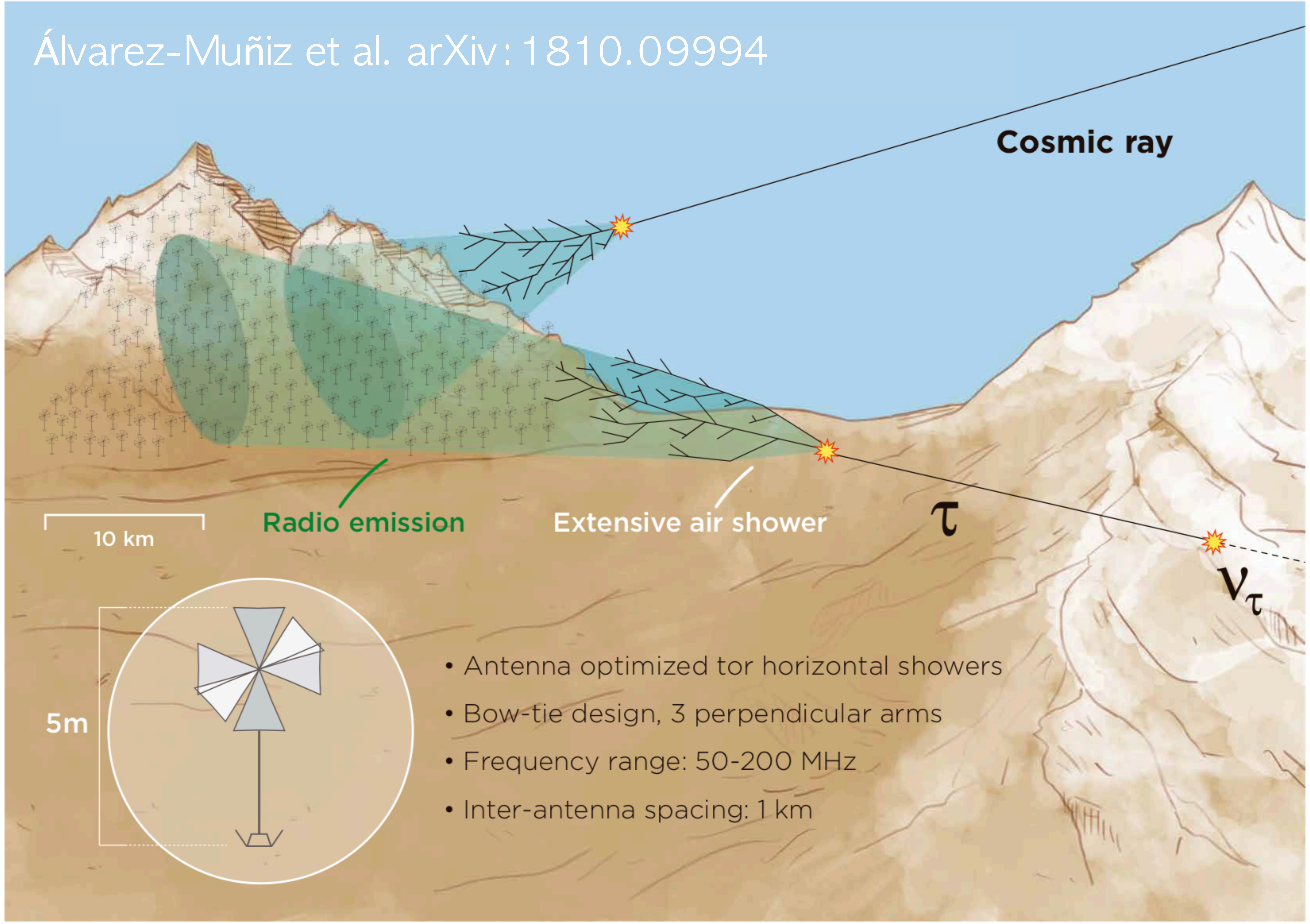
Topics on Cosmic neutrino Physics - October 2019



CνB
Solar
Terrestrial
SN 1987a
Diffuse SN
Atmospheric
AGN
GRB
GZK
$\Phi\ [\mathrm{eV}^{-1}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}\,\mathrm{cm}^{-2}]$
10^{16}
10^{10}
10^{4}
10^{-2}
10^{-8}
10^{-14}
10^{-20}
10^{-26}
10^{-32}
10^{-38}
10^{-6} 10^{-3} 10^{0} 10^{3} 10^{6} 10^{9} 10^{12} 10^{15} 10^{18} 10^{21}
E [eV]

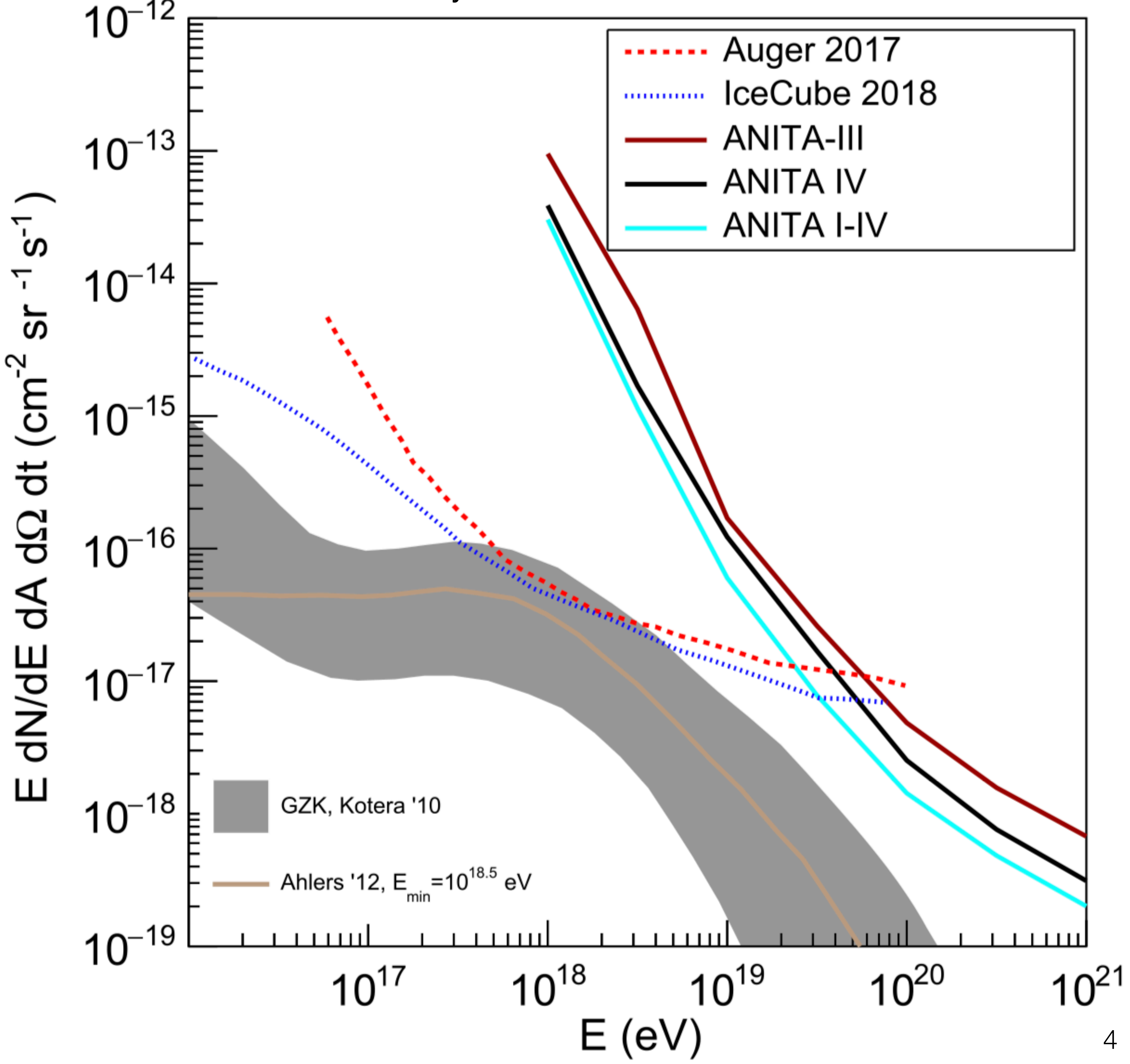
Direct detection

- Use atmosphere, mountains, volcanoes, and a sliver of the Earth as target.
- Detect radio emission from tau decay showers in the ice/atmosphere. (ANITA/GRAND/RNO/POEMMA)
- Cherenkov light from taus also detectable (POEMMA)
- Fluorescent light detection possible with precision optical detectors (ASHRA/NTA)

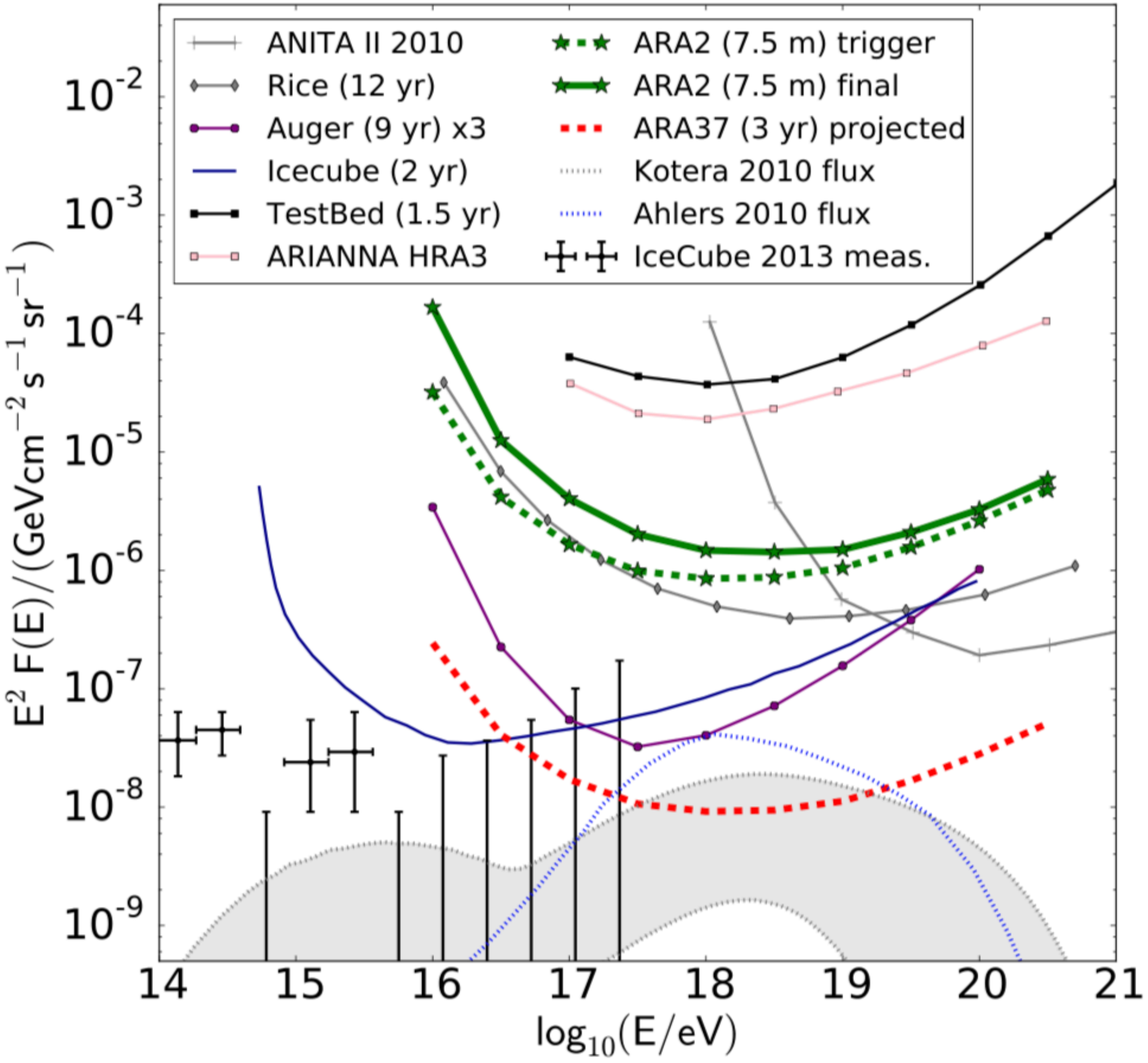


Where we stand

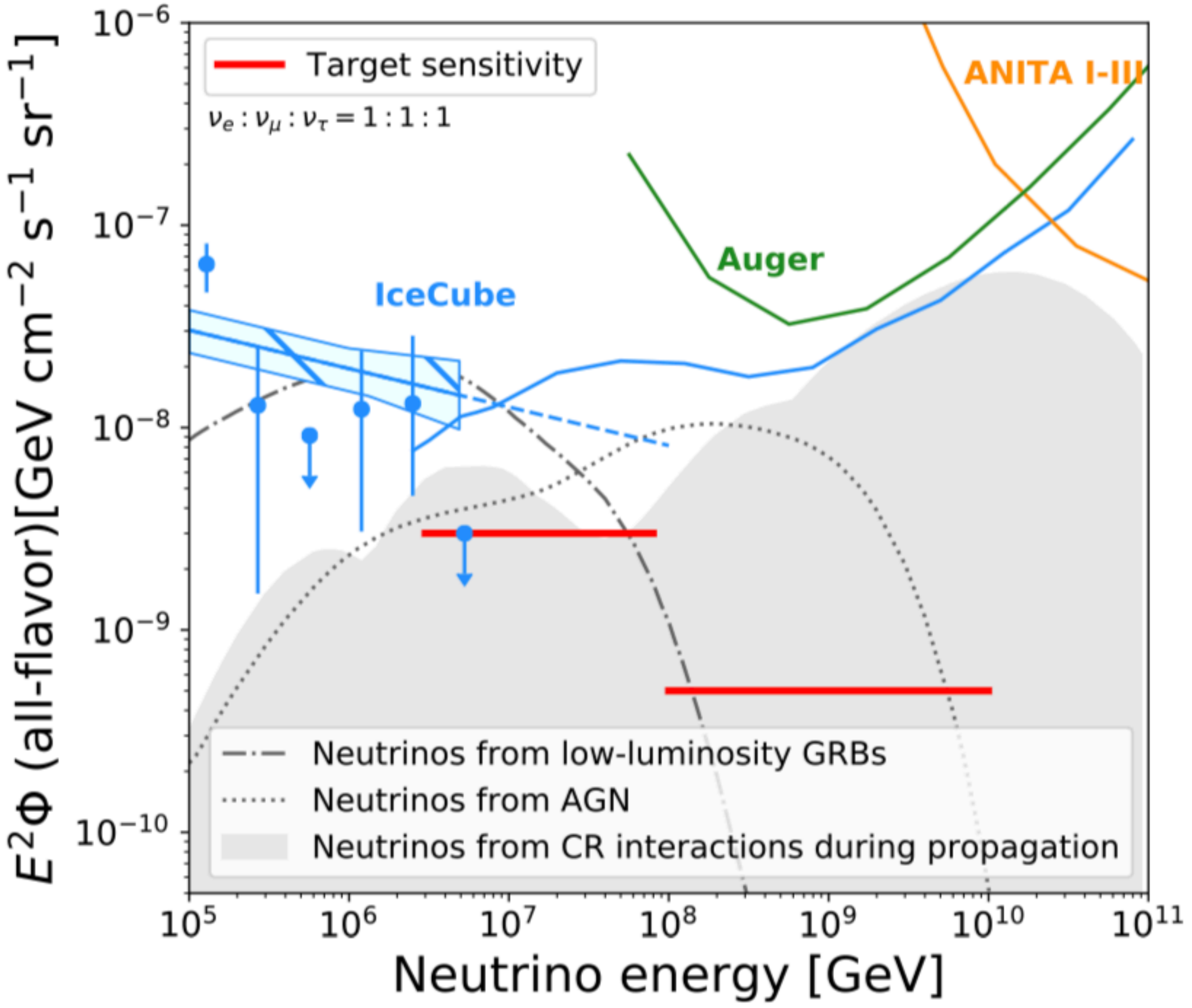
DOI: 10.1103/PhysRevD.99.122001



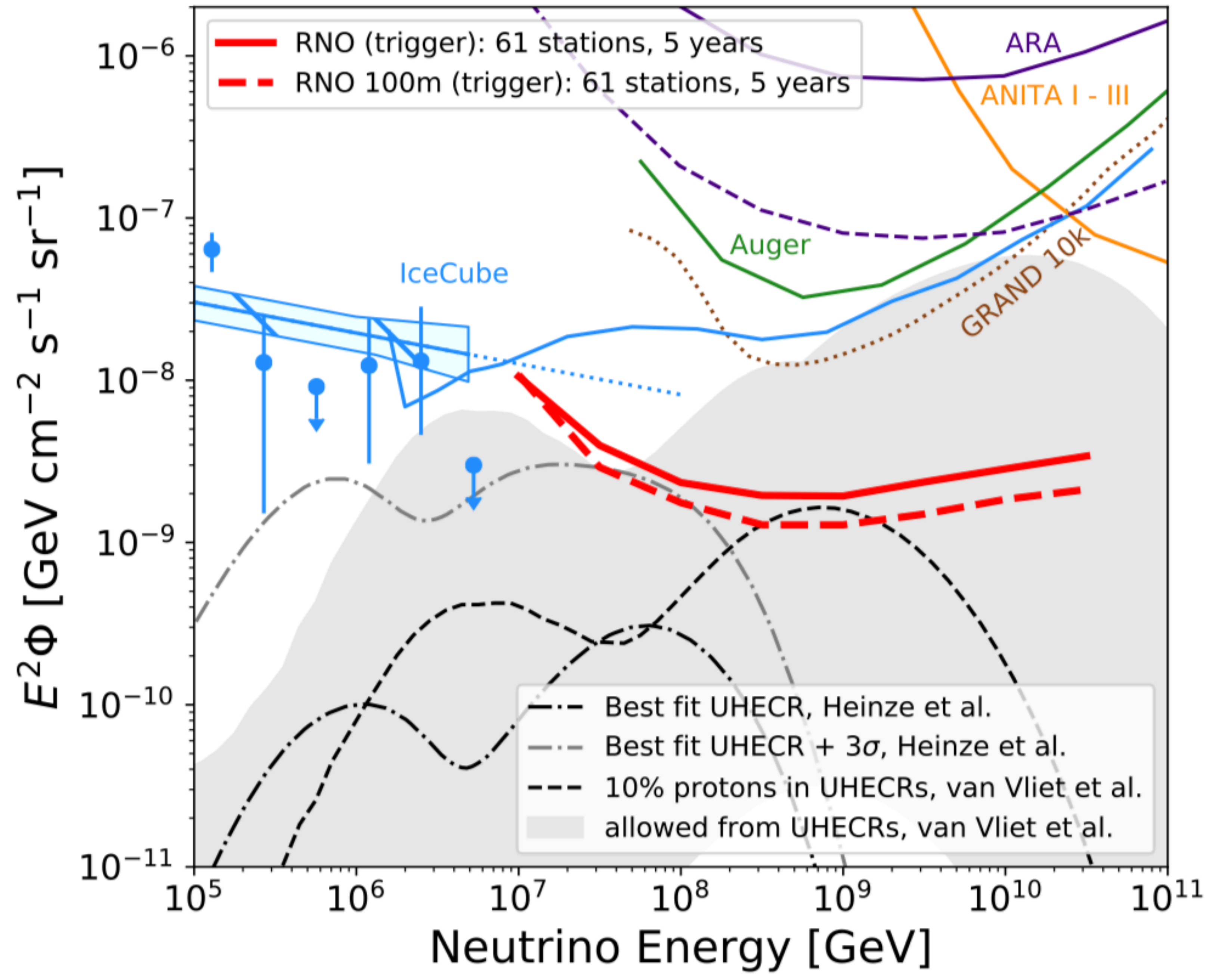
10.1103/PhysRevD.93.082003



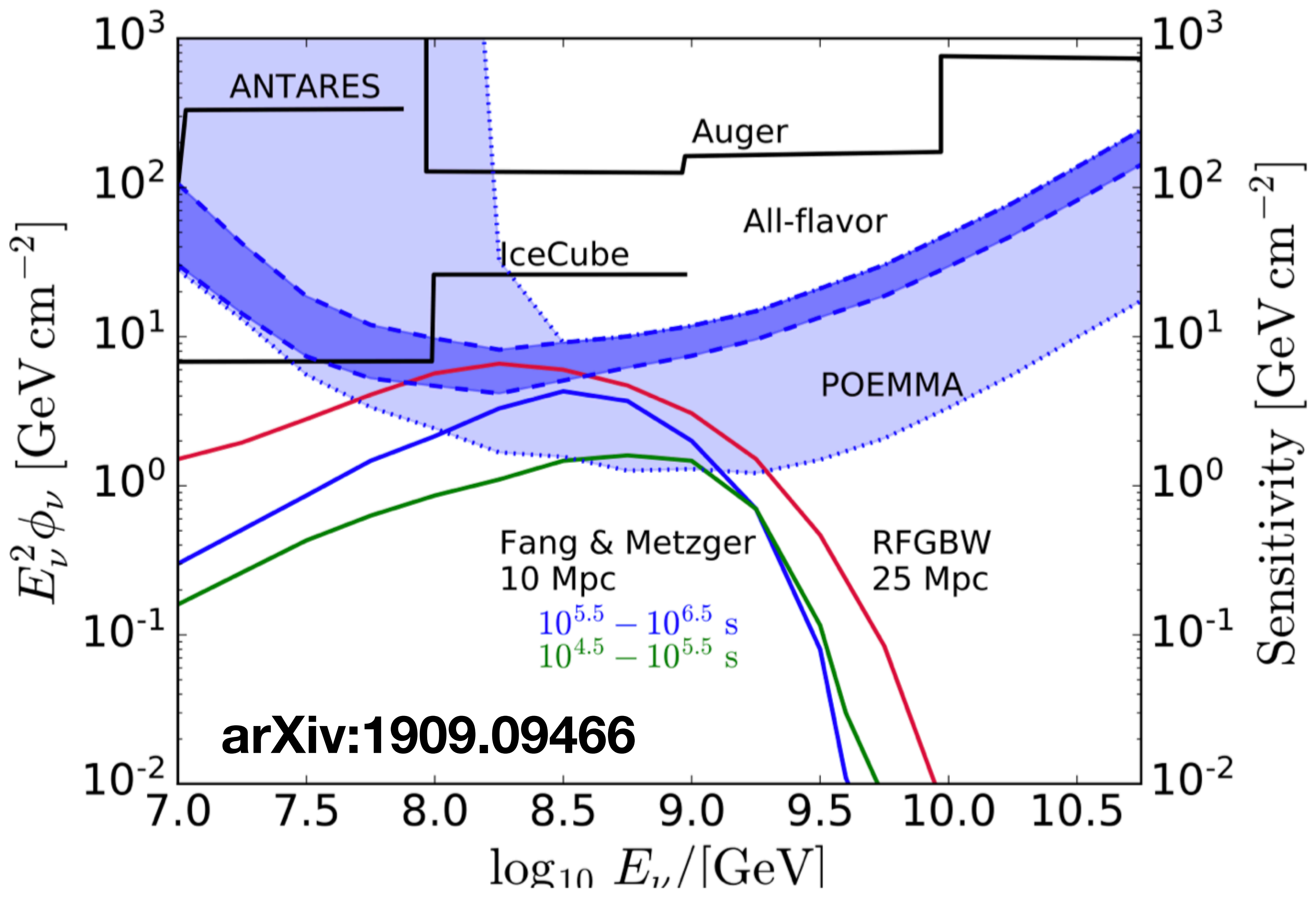
What lies ahead



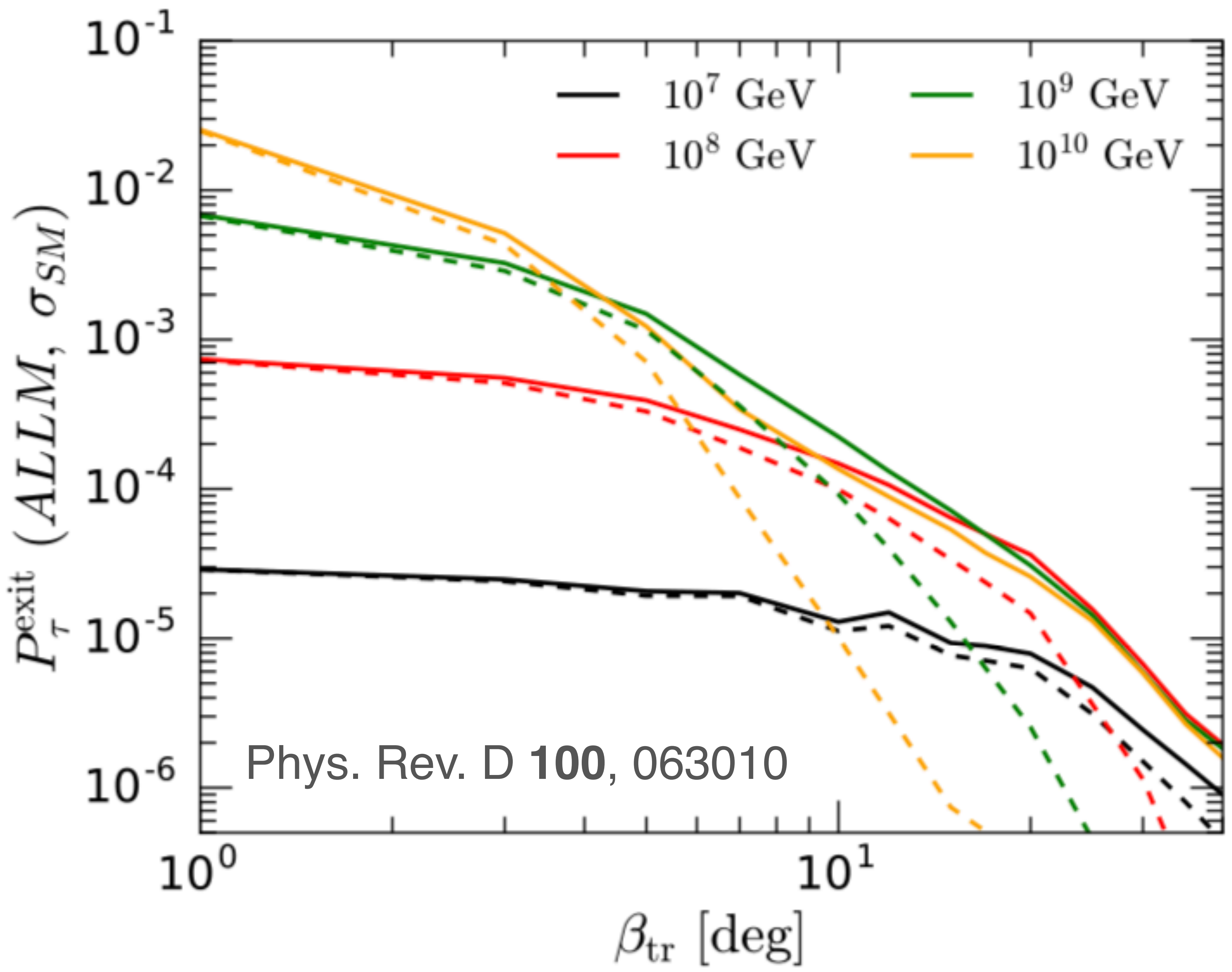
arXiv:1903.04334



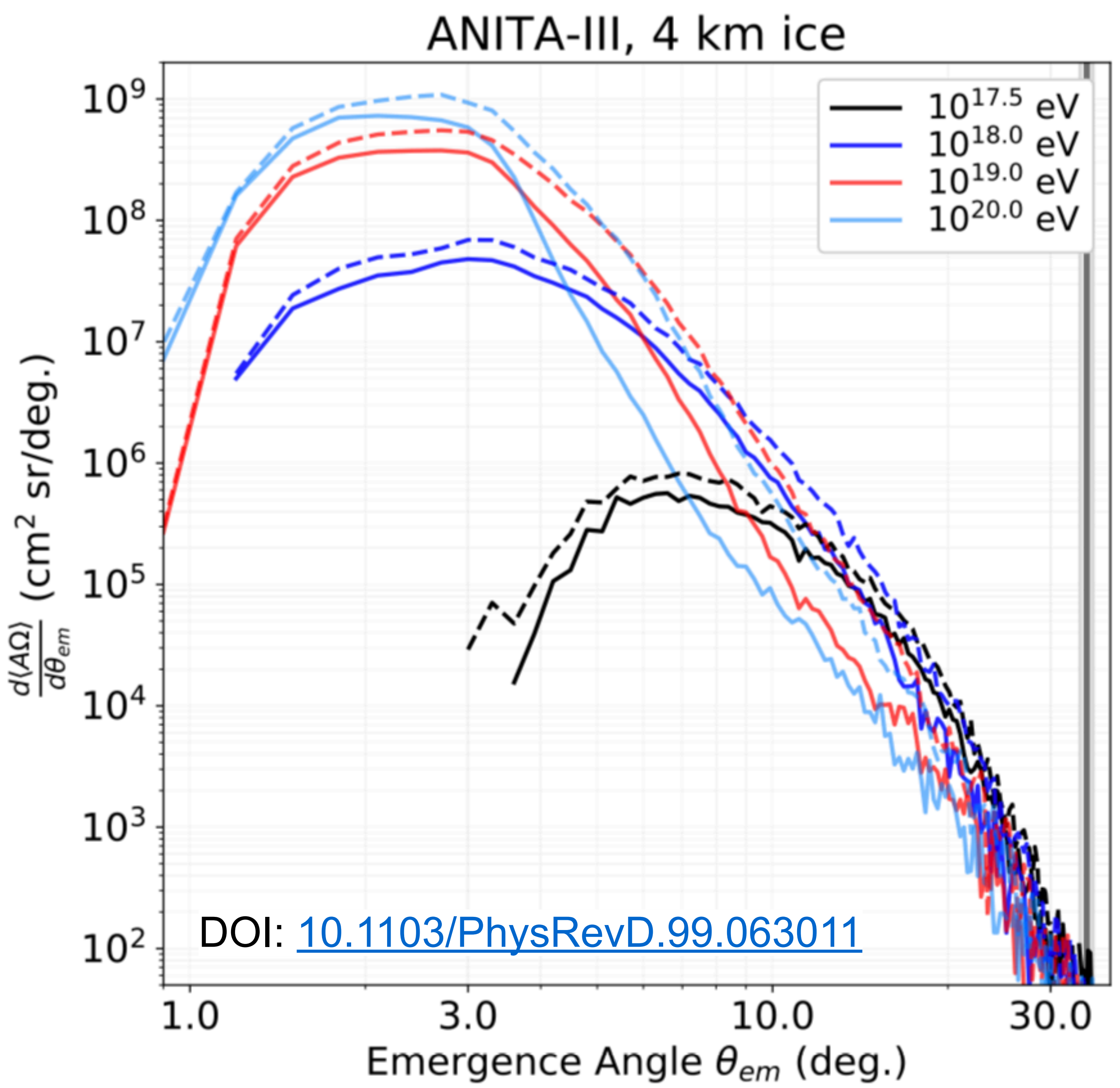
arXiv:1907.12526



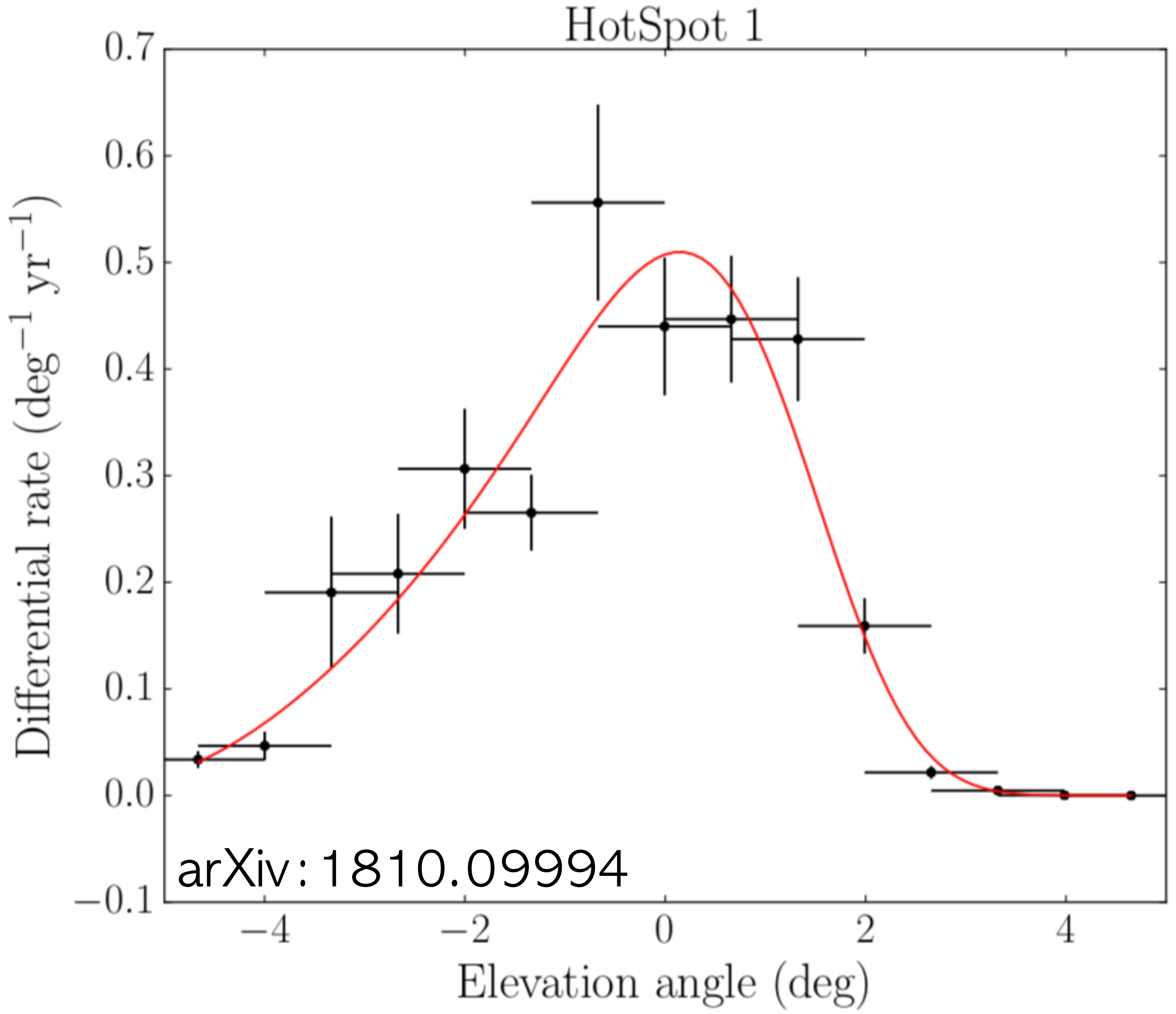
The Earth-skimming technique: Limitations



- As column depth increases, primary flux is lost.
- Emerging taus at steep angles have energies, on average, below threshold for radio detection techniques.
- Searches utilizing the Earth-skimming technique are limited to a small fraction of the sky.



ANITA Differential acceptance



Predicted GRAND rates as a function of elevation angle

Tau neutrino regeneration: A new hope

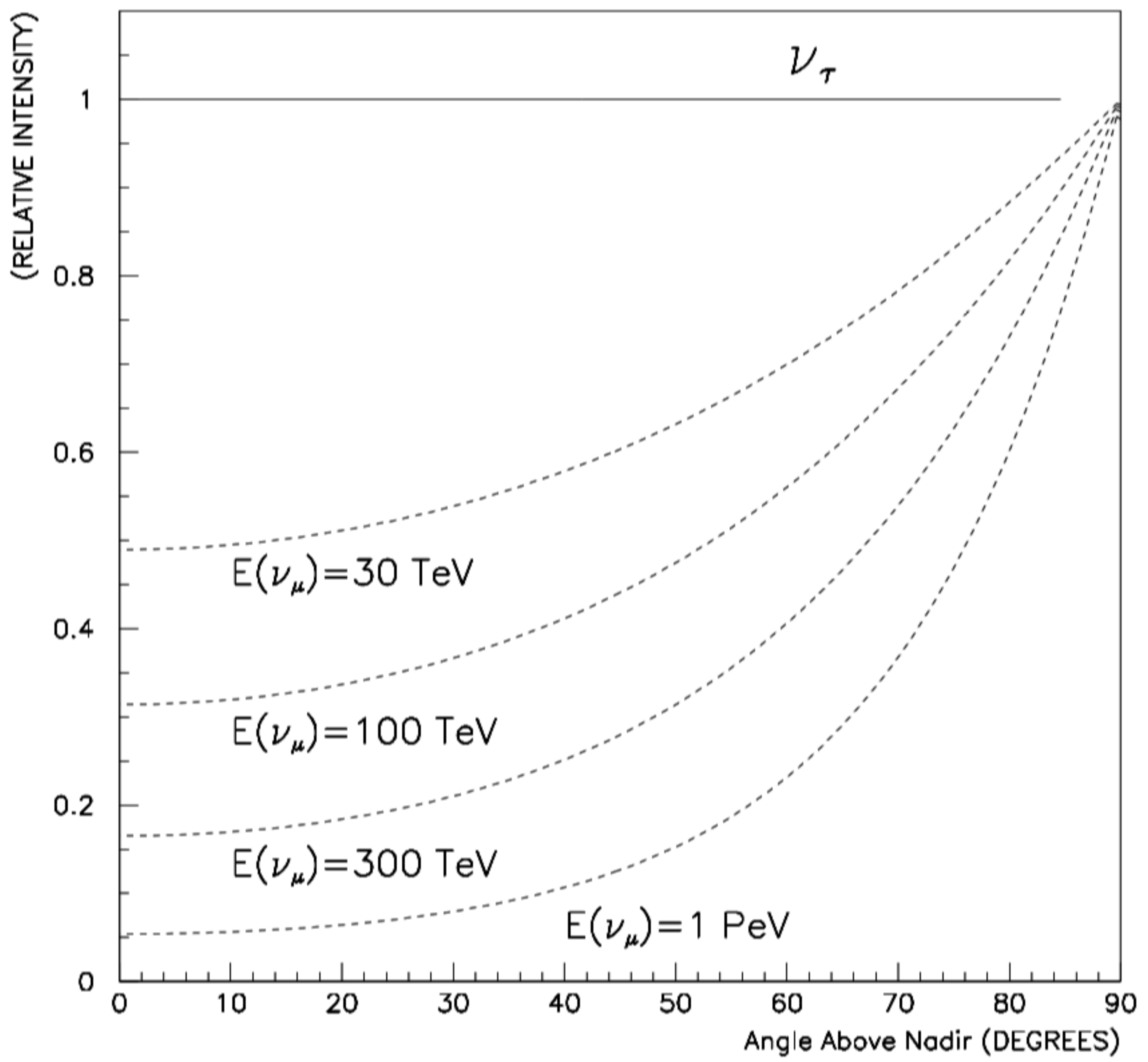
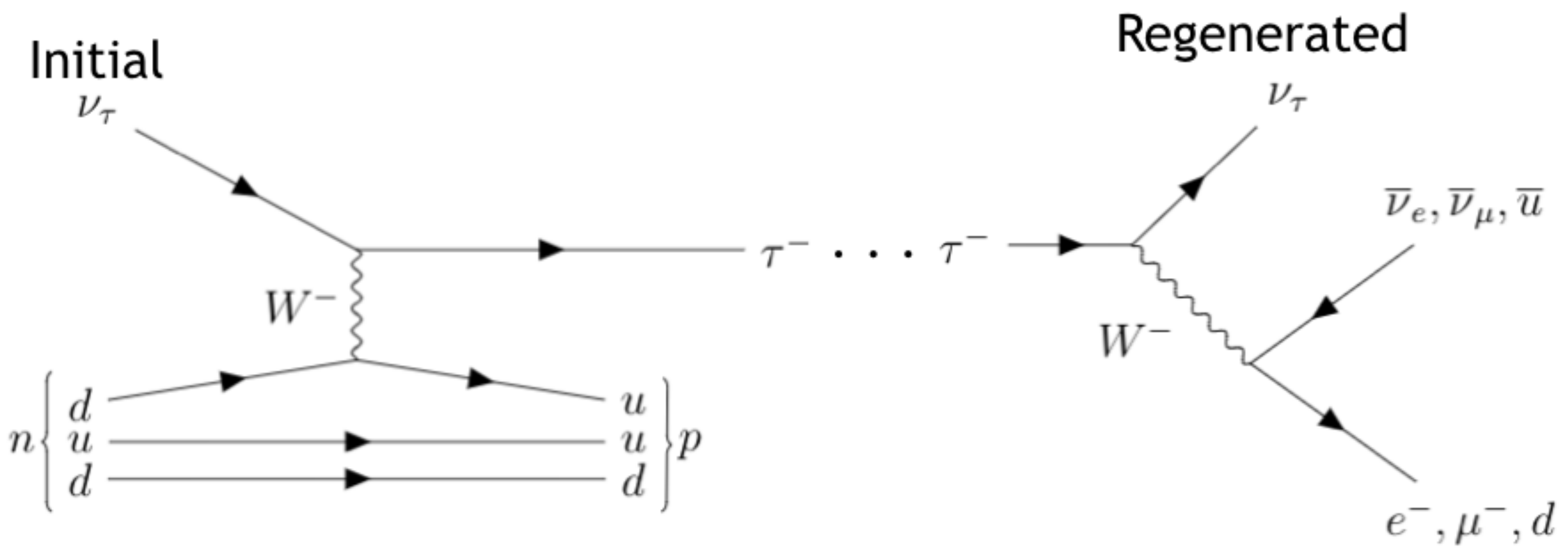


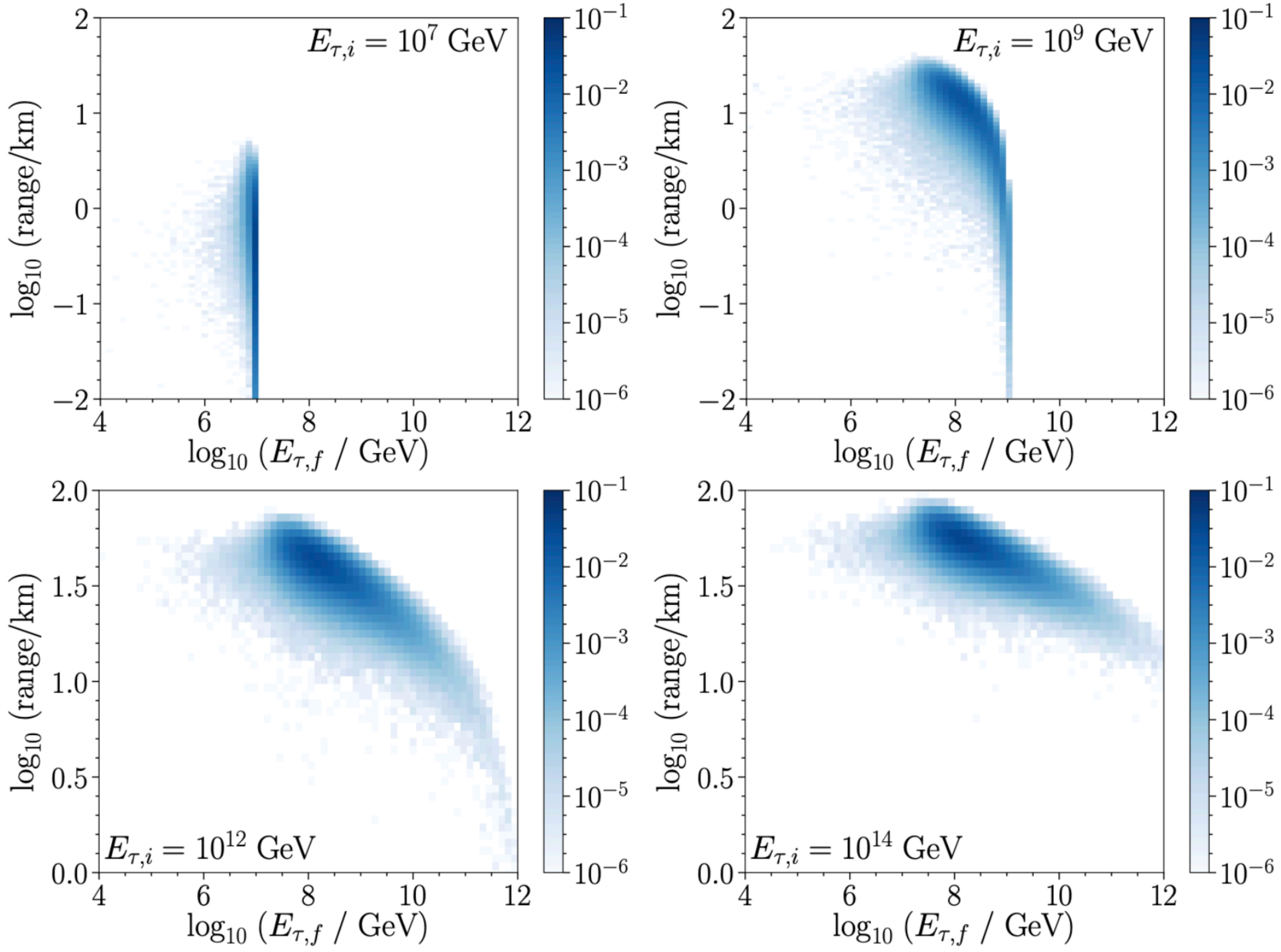
FIG. 2. Plot of the transmission of ν_μ and ν_τ through the Earth's. The transmission of ν_τ is essentially independent of their energy, as described in the text. The event rates are normalized to the maximum.

10.1103/PhysRevLett.81.4305



- Weak decays scale as ~m_ℓ^5. Tau lifetime is ~10^7 times shorter than the muon.
- Critical energy for taus (where decay- and interaction- length are equal) is ~1EeV in rock.
- Guaranteed secondary flux of tau neutrinos

Tau neutrino regeneration: A new hope



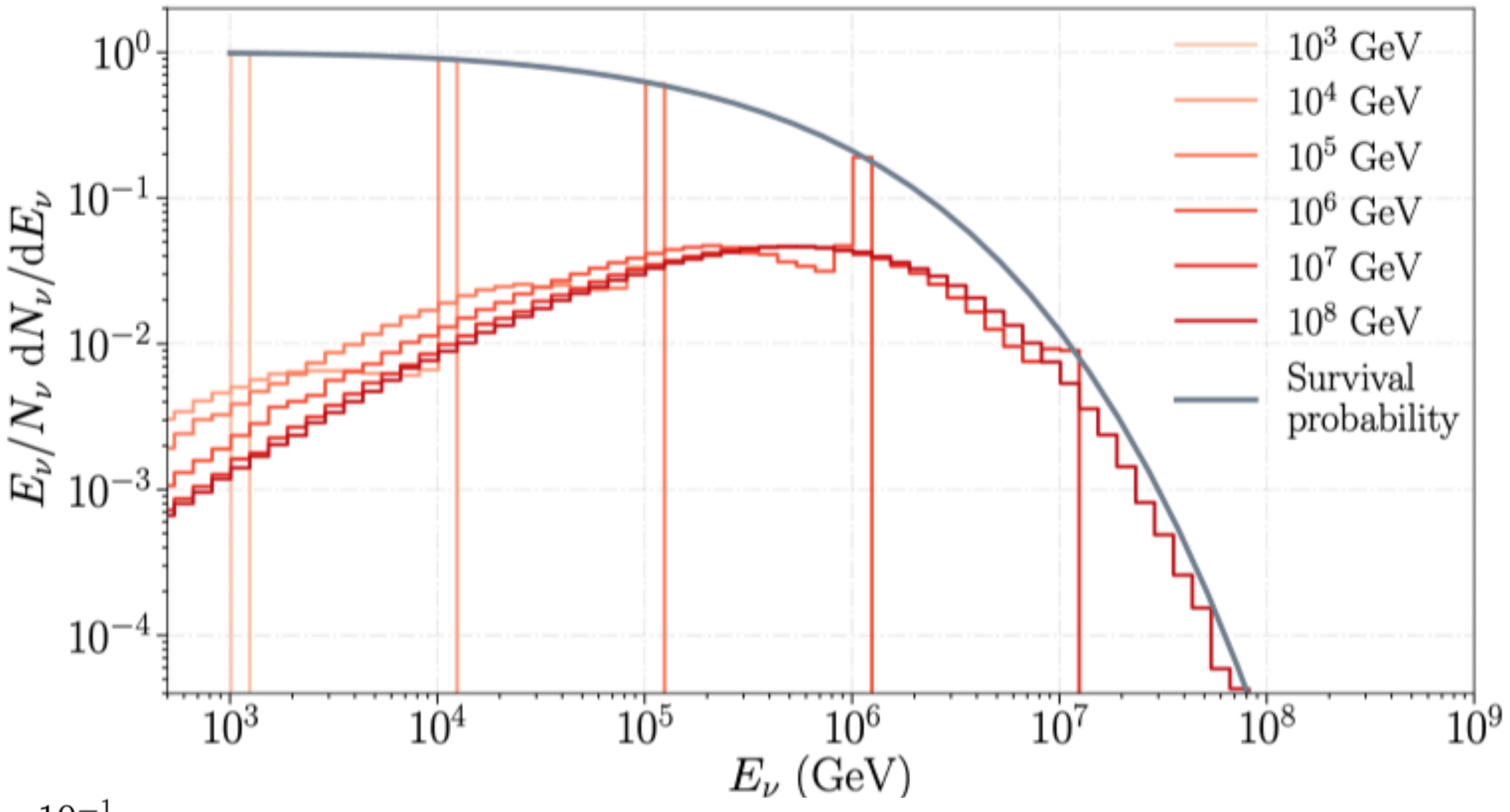
- At and above 1 EeV, energy at which taus decay asymptotes.
- Above 10 EeV, range asymptotes as well.

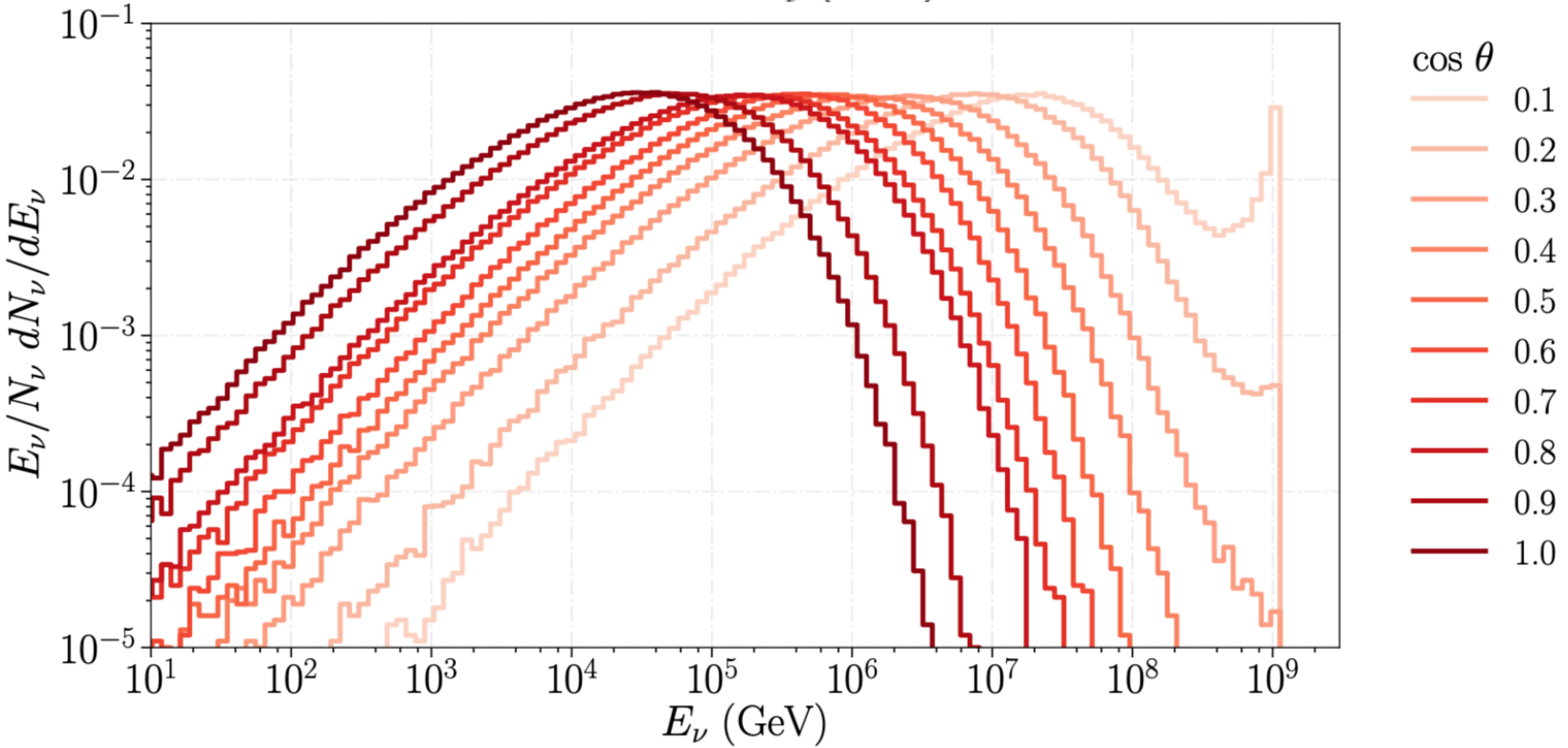
TauRunner MC

- We developed a python package to propagate EHE neutrinos and taus through the Earth. (available publicly https://github.com/IceCubeOpenSource/TauRunner)

- Neutrinos traversing the Earth undergo ~2–3 CC interactions, on average.

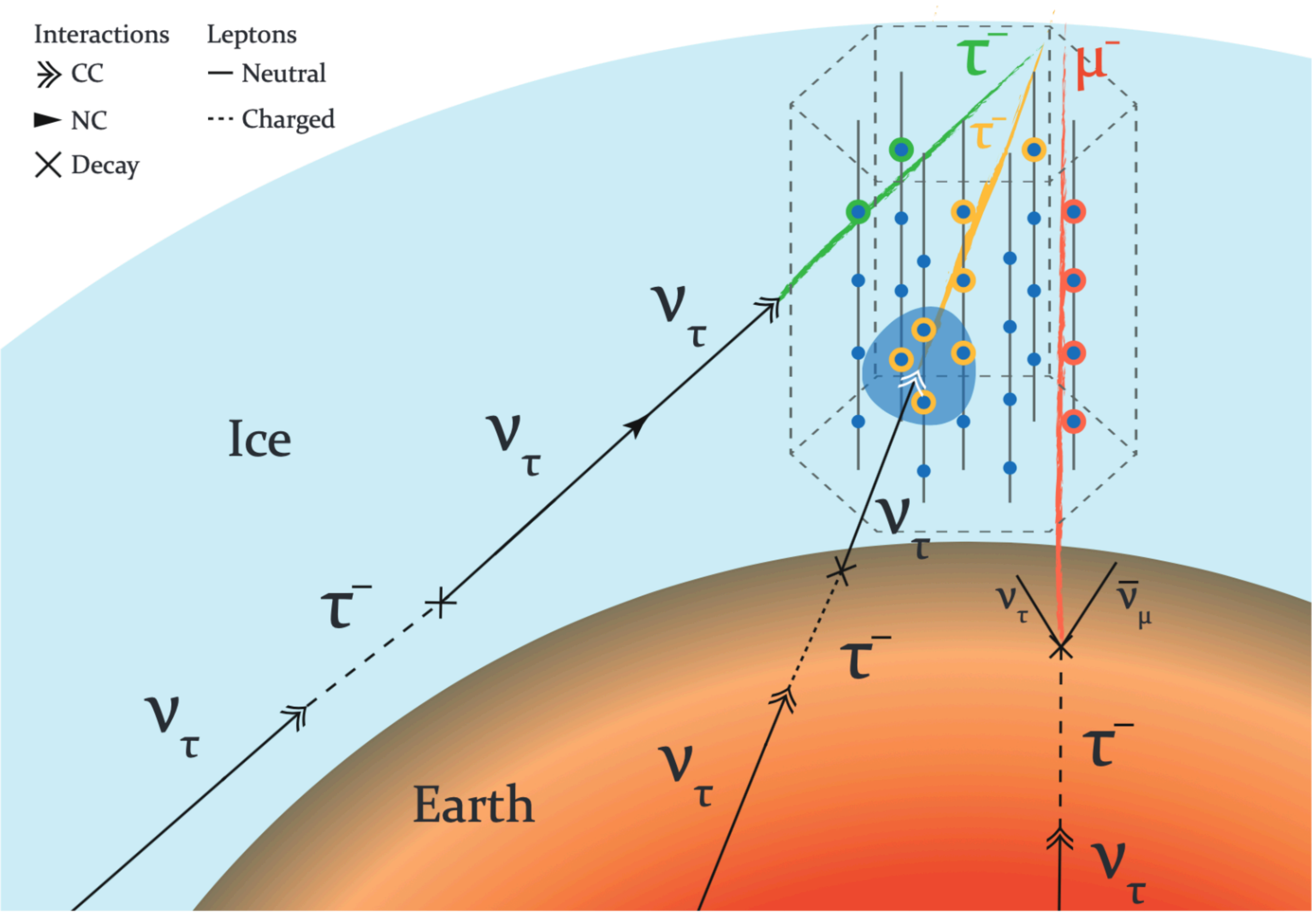
- They emerge at $\mathcal{O}$(1–100) PeV energies for most column depths, with exception of core.





Signatures of Earth-traversing EeV+ neutrinos

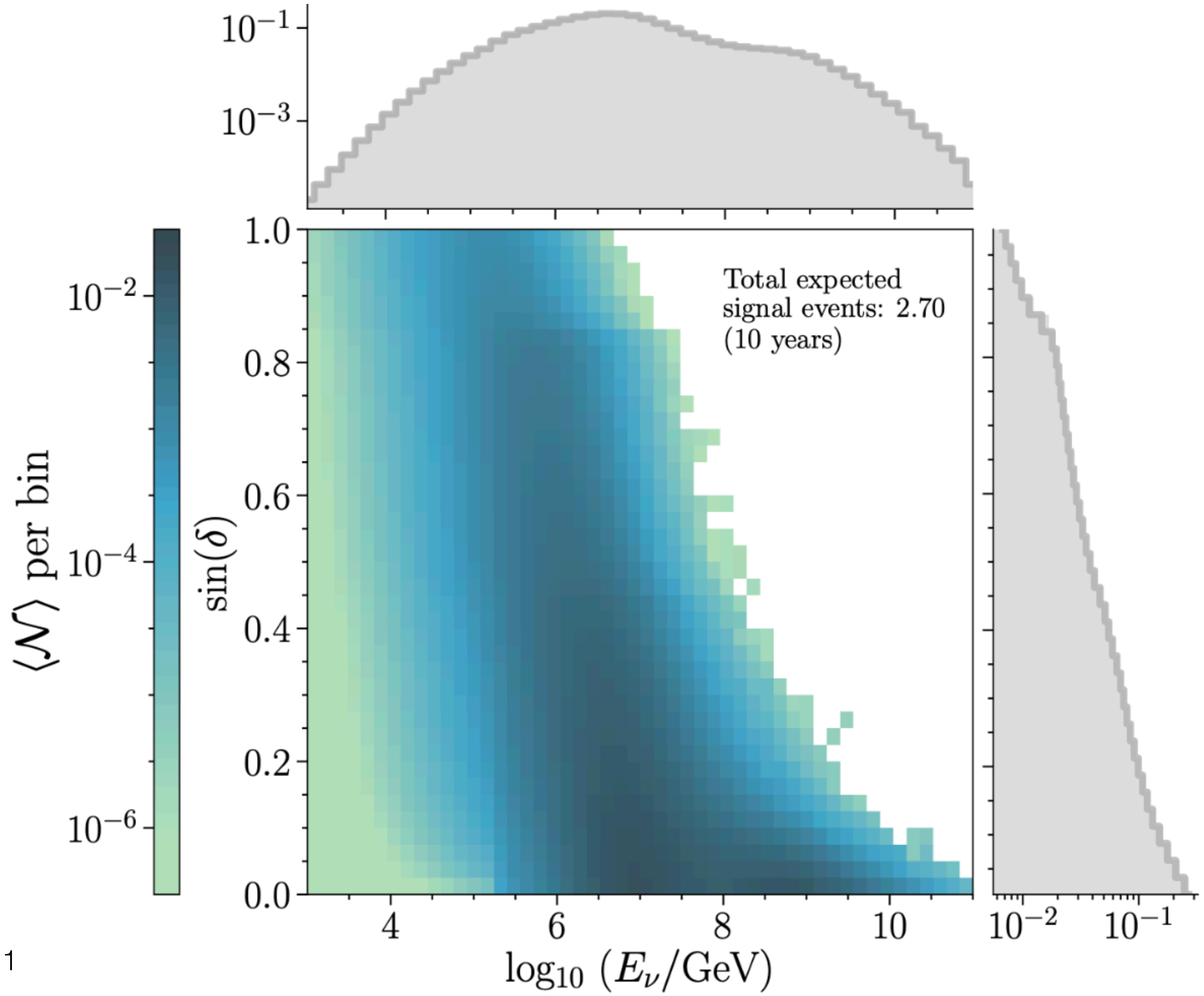
- Left: Tau tracks at and above 10 PeV.
- Center: Interaction vertex is contained in the detector. Initial cascade + outgoing track.
- Right: Tau decay to muons (18% of the time). Muons are then observed.
- NC interactions in the detector volume are possible (not shown)



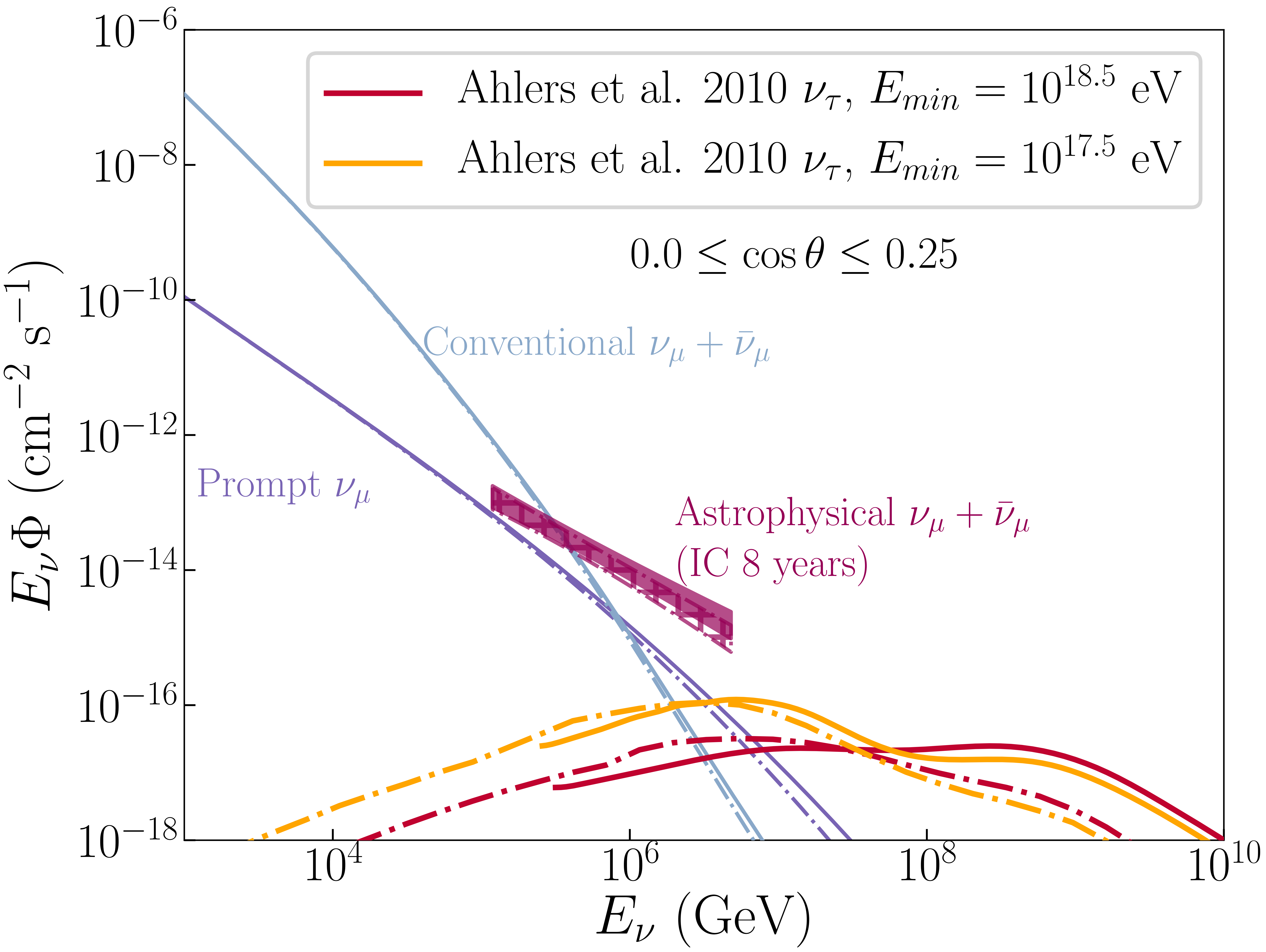
Event expectation

$$\mathcal{N}_\nu^{\mathrm{GZK}} = \int dE' d\Omega \; \Phi_\nu(E'_\nu) \Delta T \left[\sigma_{\nu N}^{CC}(E'_\nu) \cdot \frac{\Gamma_{\tau\rightarrow\mu}}{\Gamma_{total}} \cdot N_N^{CC}(E'_\nu) + \sigma_{\nu N}^{NC}(E'_\nu) \cdot N_N^{NC} \right],$$

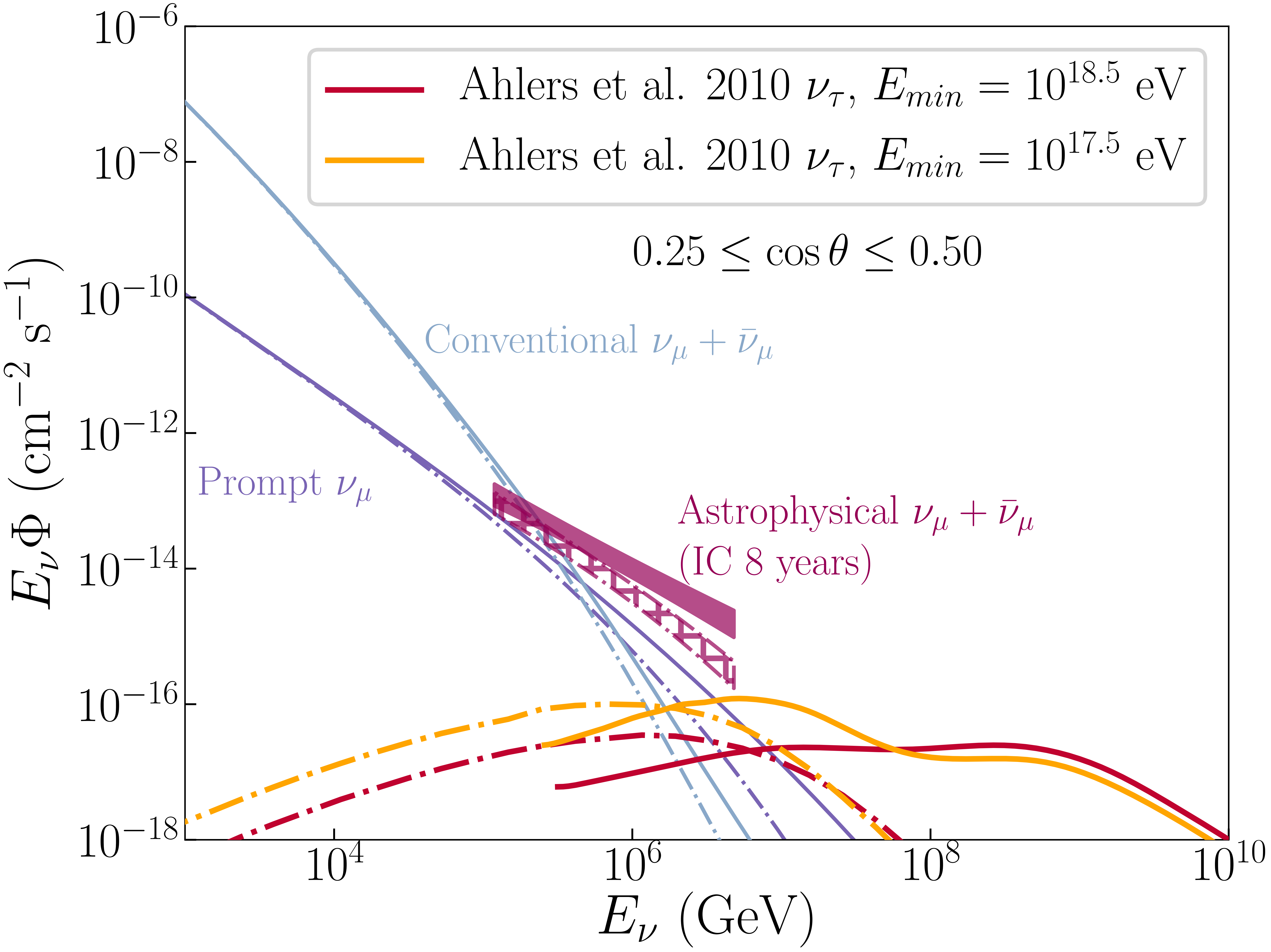
- Isotropic cosmogenic neutrino flux[1] propagated to IceCube.
- Event expectation calculated in 10 years of data (available now).
- Pileup at a few PeV.
- Earth-skimming events are one-third the total rate.



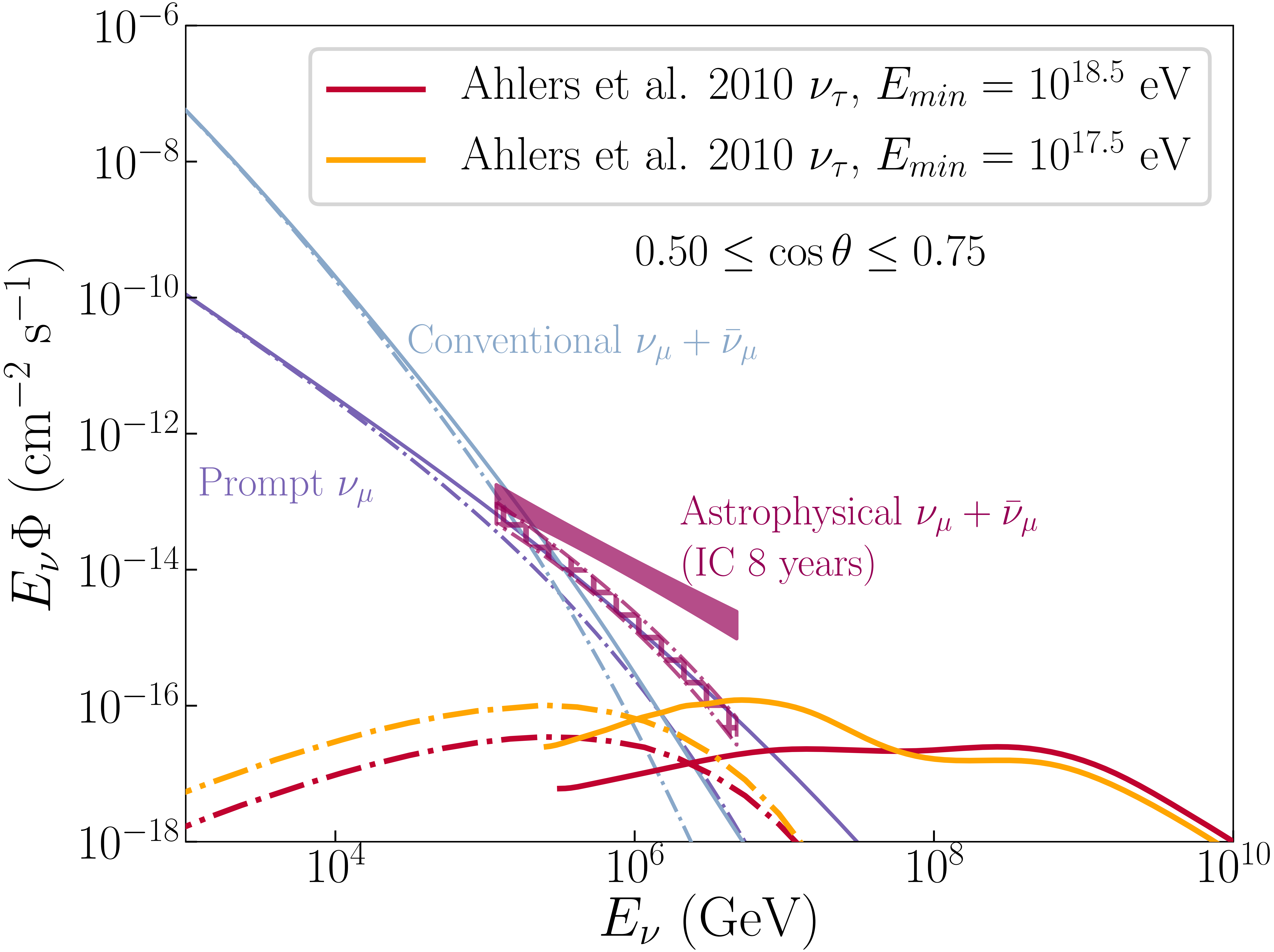
[1] arXiv:1005.2620



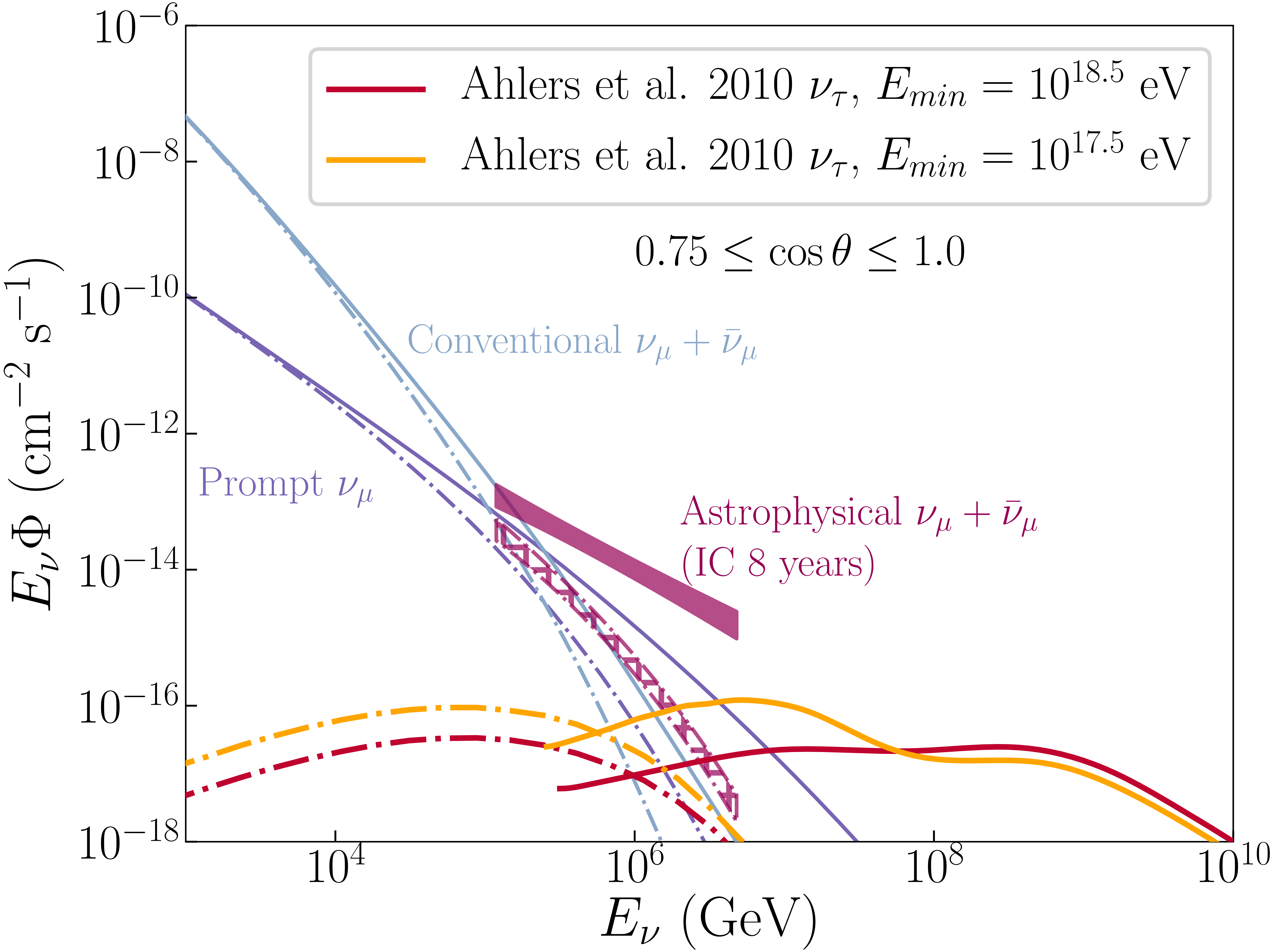
Ahlers et al. 2010 ν_τ, $E_{min} = 10^{18.5}$ eV
Ahlers et al. 2010 ν_τ, $E_{min} = 10^{17.5}$ eV
$0.0 \leq \cos\theta \leq 0.25$
Conventional $\nu_\mu + \bar{\nu}_\mu$
Prompt ν_μ
Astrophysical $\nu_\mu + \bar{\nu}_\mu$
(IC 8 years)
$E_\nu \Phi$ (cm^{-2} s^{-1})
E_ν (GeV)
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{4}
10^{6}
10^{8}
10^{10}



Ahlers et al. 2010 ν_τ, $E_{min} = 10^{18.5}$ eV
Ahlers et al. 2010 ν_τ, $E_{min} = 10^{17.5}$ eV
$0.25 \leq \cos\theta \leq 0.50$
Conventional $\nu_\mu + \bar{\nu}_\mu$
Prompt ν_μ
Astrophysical $\nu_\mu + \bar{\nu}_\mu$
(IC 8 years)
$E_\nu \Phi$ (cm^{-2} s^{-1})
E_ν (GeV)
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{4}
10^{6}
10^{8}
10^{10}



Ahlers et al. 2010 ν_τ, $E_{min} = 10^{18.5}$ eV
Ahlers et al. 2010 ν_τ, $E_{min} = 10^{17.5}$ eV
$0.50 \leq \cos\theta \leq 0.75$
Conventional $\nu_\mu + \bar{\nu}_\mu$
Prompt ν_μ
Astrophysical $\nu_\mu + \bar{\nu}_\mu$
(IC 8 years)
$E_\nu \Phi$ (cm^{-2} s^{-1})
E_ν (GeV)
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{4}
10^{6}
10^{8}
10^{10}



Ahlers et al. 2010 ν_τ, $E_{min} = 10^{18.5}$ eV
Ahlers et al. 2010 ν_τ, $E_{min} = 10^{17.5}$ eV
$0.75 \leq \cos\theta \leq 1.0$
Conventional $\nu_\mu + \bar{\nu}_\mu$
Prompt ν_μ
Astrophysical $\nu_\mu + \bar{\nu}_\mu$
(IC 8 years)
$E_\nu \Phi$ (cm^{-2} s^{-1})
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{4}
10^{6}
10^{8}
10^{10}
E_ν (GeV)

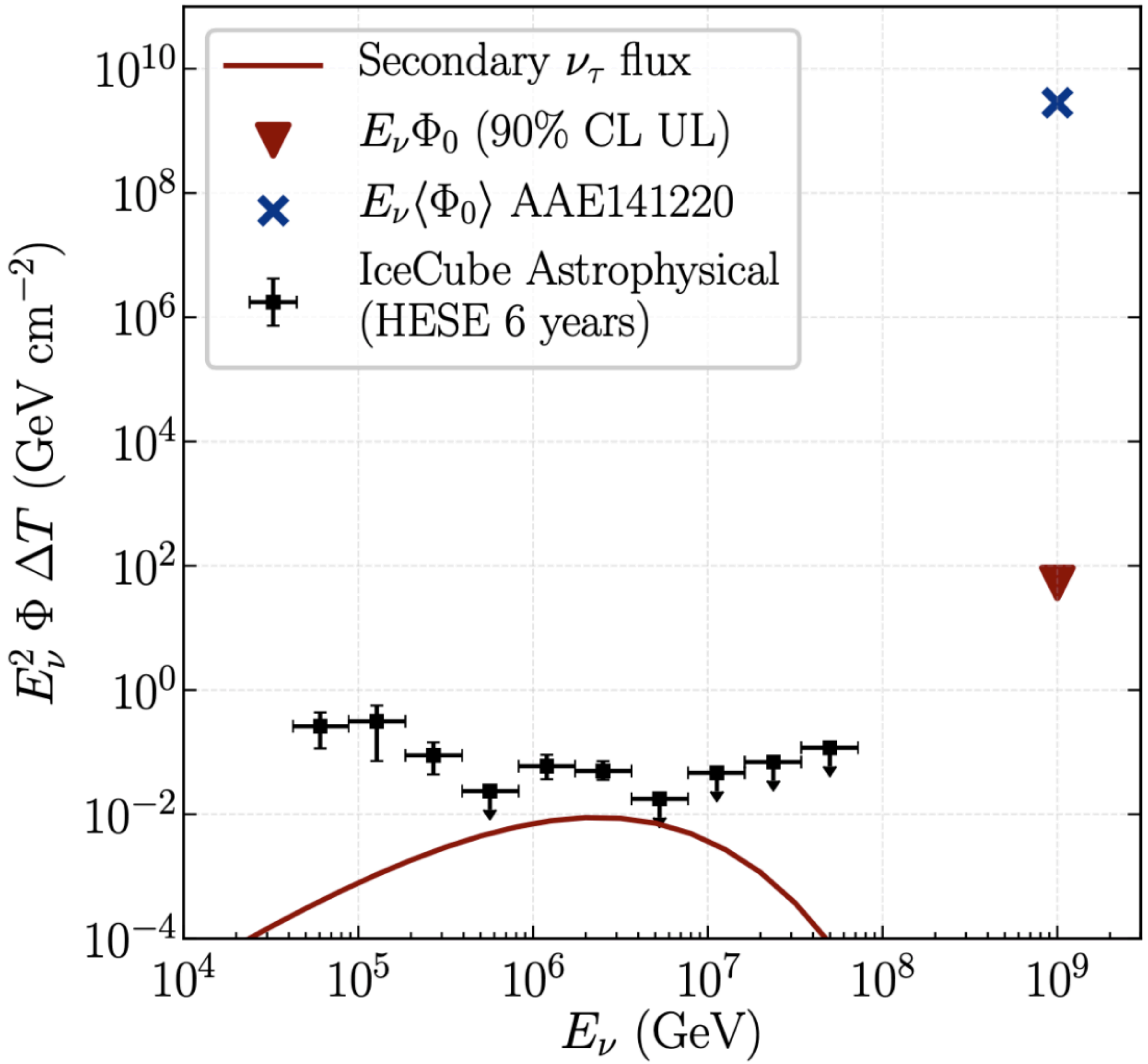
ANITA and its anomalous events

- Secondary neutrinos particularly effective for point-source fluxes.

$$\mathcal{N}_\nu = \int dE_\nu dE'_\nu \, \Phi\left(E_\nu\right) \frac{dN_\nu}{dE'_\nu}\left(E'_\nu; E_\nu\right) \xi_{acc}\left(E'_\nu\right) \Delta T \, ,$$

- Above 1 EeV, secondary neutrino distributions are degenerate with respect to primary energy.

- Allowed primary flux (maroon arrow) is orders of magnitude below expected flux to produce one event in ANITA-III (blue marker)



Conclusions

- Earth-traversing neutrinos offer a chance to indirectly detect cosmogenic fluxes.
- Astrophysical interpretation of ANITA anomalous events is severely constrained by IceCube's PeV flux.
- Rates from Earth-traversing neutrinos are twice the rates of Earth-skimming neutrinos, albeit at lower energies.
- But, cross sections at 1 PeV are well predicted. At EeV scale still unknown.
- Unique energy and zenith distributions provide additional handles.
- Depending on primary cosmic-ray composition, indirect detections could prove to be an essential complement to detectors optimized for the EeV scale.